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Impact of Technological Changes on Input Demand and Cost Functions in the Malaysian Rubber Industry

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Changes in the derived input demand and cost functions resulting from technological developments in the Malaysian rubber industry were quantitatively assessed. The specific objective was to determine the nature and magnitude of shift both in the derived input demand and cost functions associated with different levels of rubber growing technologies. The results of the analysis indicated a 12% shift in the derived input demand functions for labour, tree, fertiliser and other input expenditures when the USM technology was replaced by the HYM 1 technology. However, the reverse trend emerged when the more recent technological strata (HYM 2 and HYM 3) were compared with the HYM 1 stratum. Long-run cost functions for the HYM technological strata were found to have shifted downwards in a neutral manner. The magnitude of shift for each technological stratum, however, varied with the technological levels. The important indication of the results was that the rate of reduction in unit cost of output resulting from the introduction of the recent high-yielding technologies has been diminishing given the existing factor prices. Future research policies need to take account of this diminishing rate of downward shift in the long-run cost function for rubber production.

Since 1926, after the RRIM was established, new technology on rubber growing has been the direct result of nationally co-ordinated research. Historically, rubber research has been conducted within the framework of a labour-surplus economy but in the last decade, labour has become increasingly scarce and expensive. This trend is expected to continue. Under these circumstances research planners need to consider whether it is necessary to change the direction of current and future research. In this context it is essential to examine the impact of past research and hence technological progress on the various input demand and cost functions.

This paper analyses two rather different aspects of this problem. First, the nature of the shift in the input demand and cost functions are considered. This analysis provides information about whether past research has produced technology biased towards one or more input factors. The second aspect examined is the direction and extent of shift in the cost functions and hence the effect of past technology advances on the unit cost of producing raw rubber.

Deriving Input Demand and Cost Functions

The procedure adopted in this study is based on those discussed by Nerlove[1].

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Some variations of this procedure have been adopted from Heady and Dillon[2], Henderson and Quandt[3] and Sidhu[4]. The essence of the methodology is to assume that the basic underlying production process may be described by a Cobb-Douglas production function. Given this assumption, it is possible to derive directly the reduced form of input demand and cost functions.

The Shephard duality theorem[5,6] states that each production function has a minimum cost function as its dual which relates factor prices to the cost of output. Nerlove argues that under the cost minimisation assumption, the cost function and the production function are simply two different but equivalent ways of looking at the same thing.

To derive the input demand and cost functions relevant to the present analysis, the modified Cobb-Douglas functional form is adopted. The detailed specification of the Cobb-Douglas production function adopted for the Malaysian rubber growing industry is written as follows:

$$Y = \alpha_0 N^{\alpha_1} . T^{\alpha_2} . F^{\alpha_3} . E^{\alpha_4} e^{(\delta + \mu)} \qquad \ldots 1$$

where Y is the annual rubber output per field measured in thousand kilogrammes of first grade ribbed-smoke sheet (RSS 1) equivalent

N is the harvesting labour measured in total number of tappings

T is the total index value for tappable trees per field corrected for age effects*

F is the total amount in kilogrammes of fertilisers applied per field per year

E is the other input expenditure measured in Malaysian ringgit

e is the error variable

δ is the coefficient of a dummy variable which is designed to capture the shift of the function

α_o is the multiplicative constant term

α_i is the coefficient of independent variables

μ is the random disturbance term independently distributed with zero mean.

The total cost of rubber production for any particular field $j(TC_j)$ can be expressed as

$$TC_j = P_n N_j + P_t T_j + P_f F_j + P_e E_j \qquad \ldots 2$$

where P_n, P_t, P_f and P_e are the prices of harvesting labour, trees, fertilisers and other input expenditure respectively, and j represents the particular field. Minimisation of the cost function *(Equation 2)* subject to the Cobb-Douglas function *(Equation 1)* implies the following marginal productivity conditions:

$$\frac{P_n N_j}{\alpha_1} = \frac{P_t T_j}{\alpha_2} = \frac{P_f F_j}{\alpha_3} = \frac{P_e E_j}{\alpha_4} \qquad \ldots 3$$

Solving the marginal productivity conditions of *Equation 3* and the production function of *Equation 1* simultaneously, the reduced form of the input demand

* Tree index value T is derived by multiplying the total number of trees per field by the tree value V_t. V_t is calculated based on the formula $V_t = \dfrac{\sum_{t=1}^{t=3} q_t - \sum_{t=1}^{t} q_t}{30}$ where t is the tapping age of the tree and q_t is the yield of the rubber tree.

functions for N, T, F and E are obtained. The derived input demand functions for N, T, F and E are given by *Equations 4, 5, 6* and *7* respectively:

$$N = \frac{A_n Y^{1/\gamma} P_n^{\alpha_1/\gamma} P_t^{\alpha_2/\gamma} P_f^{\alpha_3/\gamma} P_e^{\alpha_4/\gamma} e^{-(\delta+\mu)/\gamma}}{P_n} \quad \ldots 4$$

$$T = \frac{A_t Y^{1/\gamma} P_n^{\alpha_1/\gamma} P_t^{\alpha_2/\gamma} P_f^{\alpha_3/\gamma} P_e^{\alpha_4/\gamma} e^{-(\delta+\mu)/\gamma}}{P_t} \quad \ldots 5$$

$$F = \frac{A_f Y^{1/\gamma} P_n^{\alpha_1/\gamma} P_t^{\alpha_2/\gamma} P_f^{\alpha_3/\gamma} P_e^{\alpha_4/\gamma} e^{-(\delta+\mu)/\gamma}}{P_f} \quad \ldots 6$$

$$E = \frac{A_e Y^{1/\gamma} P_n^{\alpha_1/\gamma} P_t^{\alpha_2/\gamma} P_f^{\alpha_3/\gamma} P_e^{\alpha_4/\gamma} e^{-(\delta+\mu)/\gamma}}{P_e} \quad \ldots 7$$

where $A_i = \alpha_i \{\alpha_0 \alpha_1^{\alpha_1} \alpha_2^{\alpha_2} \alpha_3^{\alpha_3} \alpha_4^{\alpha_4}\}^{-1/\gamma}$

and $\gamma = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4$

By substituting the derived input demand functions for N, T, F, and E into the total cost function *Equation 2*, one can derive the reduced form of the cost function as shown below:

$$TC_j = A Y_j^{1/\gamma} P_n^{\alpha_1/\gamma} P_t^{\alpha_2/\gamma} P_f^{\alpha_3/\gamma} P_e^{\alpha_4/\gamma} e^{-(\delta+\mu)/\gamma} \quad \ldots 8$$

where $A = A_n + A_t + A_f + A_e$

$$= \gamma \{\alpha_0 \alpha_1^{\alpha_1} \alpha_2^{\alpha_2} \alpha_3^{\alpha_3} \alpha_4^{\alpha_4}\}^{-1/\gamma}$$

The basic estimated equation for the cost function can be obtained by taking the natural logarithms of *Equation 8*. The form of the cost equation which can be estimated by ordinary least squares (OLS) method is *Equation 9:*

$$\ln TC_j = \ln A + 1/\gamma \ln Y_j + \alpha_1/\gamma \ln P_n + \alpha_2/\gamma \ln P_t + \alpha_3/\gamma \ln P_f + \alpha_4/\gamma \ln P_e - \delta/\gamma - \mu/\gamma \quad \ldots 9$$

The underlying assumption for estimating *Equation 9* is that both the output Y and price variables must be assumed to be exogenous variables. This assumption may be justified by emphasising the following characteristics of both the rubber growing industry and cost structure of the estate sector:

- The amount of rubber produced is essentially controlled by the system adopted by the estate managers. The output depends on the various input factors and type of cultivar. Thus, the output is largely pre-determined in *any given time period.*
- Revenue from sales depends on international rubber prices set by market forces.
- Many of the variable inputs (e.g. harvesting and maintenance labour, fertilisers, chemicals and equipment) are obtained from open markets where their prices are competitively determined.
- The tapping or harvesting labour wage rate is set periodically by negotiations between the National Union of Plantation Workers (NUPW) and the Malaysian Agricultural Producers Association (MAPA). These agreements usually extend over a period of years. Under these conditions wages for harvesting labour appear to be determined competitively in the long run.

Analytically, the reduced form of cost function approach such as in *Equation 9* has several advantages over the production function method. First, it yields direct estimates of the long-run cost function and the parameter γ of the function provides a direct single estimate of the physical returns to scale simply by taking the reciprocal of the coefficient of $\ln Y$. Since the value of γ is equal to the sum of α_1, α_2, α_3 and α_4, the output elasticities of N, T, F and E can be obtained from the coefficients[5] of P_n, P_t, P_f and P_e respectively. Due to the fundamental duality between cost and production functions, the unique relationship between the cost function and underlying production function is assured[1,5]. Secondly, the inclusion of input prices directly into the cost function enables one to obviate some common problems associated with the statistical estimation of the long-run cost function[1]. The use of the reduced form cost function overcomes the need to deflate cost figures cross-sectionally or over the time period studied. Thirdly, since all the independent variables can be viewed as exogenous, the coefficients of Y, P_n, P_t, P_f and P_e can be estimated by the method of ordinary least-squares and there is no problem of identification[4]. Fourthly, since there is usually little multicollinearity among factor prices, the usual problem of high multicollinearity associated with the production function approach does not arise with empirical cost function estimation. Finally, in the present case, assuming a Cobb-Douglas production function underlies the production process and hence the cost function, dummy variables can be introduced to compare the nature and degree of differences between cost functions for different technological strata. These can be estimated from the coefficient of the term δ/γ.

Data Sources and Levels of Technology

All the data used in this study were collected from the estate sector and pertain to the three production years 1964, 1970 and 1976. The basic sources of data were the annual surveys of estates conducted by the Rubber Research Institute of Malaysia (RRIM). Stratified random samples were selected from the estates' population. The benchmark survey conducted by the RRIM Costing and Management Group during the period 1966-7, but relating to the 1964 production year, was used as the basis for constructing the three data sets used in the present analysis[7]. Although the RRIM Costing and Management Group conducted surveys of estates on an annual basis after 1966/7, the estates included in the subsequent sample surveys were not entirely consistent with the 1964 sample. For the purposes of this study data were required for a consistent sample of fields for 1964, 1970 and 1976. Therefore, the first author undertook a separate survey of estates. In addition, certain information was made available by the RRIM Commercial Registration Unit. However, despite every effort, it was not possible to compile data for 1970 and 1976 for every field included in the 1964 sample survey due to replanting, change of ownership and subdivision of estates into smallholdings. Since no new fields were added to the sample after 1965, the sample size dropped from 911 fields in 1964 to 731 in 1970 and 619 in 1976.

Preliminary investigation identified four distinct levels of embodied technology co-existing in the 1964 production year[8]. As the most important technological feature of each level or stratum was the class of cultivars involved and the associated package of improved techniques used during the immature phase, the four strata have been labelled USM (*i.e.* unselected seedling material) and HYM 1, HYM 2 and HYM 3 (*i.e.* high-yielding material recommended for commercial plantings during three different time periods). *Table 1* depicts the classification

TABLE 1. CLASSIFICATION OF CULTIVARS INTO DIFFERENT TECHNOLOGICAL STRATA

Technological stratum	Cultivar	Characteristics
USM	Unselected seedlings	Original technology introduced to the Malaysian rubber industry
HYM 1	Tjir 1, Tjir 16, PB 86, Pil B84, PB 25	Pre-World War II high-yielding technology (1930–42)
HYM 2	RRIM 501, RRIM 513, PR 107, GL 1, PBIG/C, PBIG/D, PBIG/E, PBIG/F, PBIG/G, PBFB/A, PBFB/B, Ch IG/B, Ch IG/E, Tjir 1M, Tjir 1 illegitimate	Immediate post-war high-yielding technology (1945–59)
HYM 3	PB 5/51, GT 1, RRIM 600, RRIM 623, RRIM 605, PBIG/GG1, PBIG/GG2	Recent high-yielding technology (since 1960)

of cultivars into different technological strata and their associated characteristics.

Figure 1 presents the general framework within which the analysis has been conducted. The cross-sectional data for 1964 permit a comparison of performance between four different levels of embodied technology. However, since the USM technology was rapidly becoming obsolete, there were insufficient USM fields in the 1970 and 1976 samples to allow for meaningful analysis. Thus the comparisons made in the 1970 and 1976 production years were limited to the three HYM strata.

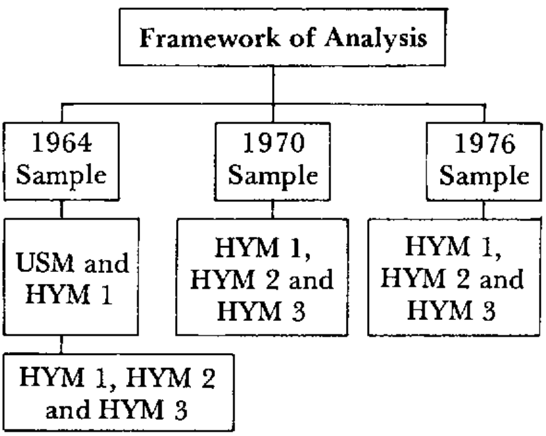

Figure 1. Summary of framework of analysis.

Empirical Comparisons of the Derived Input Demand Functions

This section compares the empirical results of derived input demand functions for the various technological strata. The main objectives were to determine the magnitude of the change in the input demand functions: first, between the USM and the HYM 1 technological strata in the 1964 production year; and secondly between the high-yielding technological strata (*i.e.* HYM 1, HYM 2 and HYM 3) in 1964, 1970 and 1976.

Production function analysis conducted by Yee[9], and the results shown later indicated that in both the above cases, constant returns to scale with respect to conventional inputs and neutral shifts in the production functions prevailed. From these results the equations for derived input demand functions of N, T, F and E *(Equation 4 to 7)* were simplified by equating γ to 1. Thus, the four derived input demand functions were written without the γ parameter and assuming that $\gamma = \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 = 1$.

Derived input demand functions of USM and HYM 1. To determine the extent of the change in input demand functions when moving from USM to HYM 1 technology, the derived input demand functions of N, T, F and E were obtained from the USM and HYM 1 data sub-sets for 1964. Restricting the production function fitted to the pooled USM and HYM 1 data sub-sets to constant returns to scale (by dividing each of the variable by N), least-squares regression gives the following results:

$$\ln\left(\frac{Y}{N}\right) = 0.1887 + \underset{(0.0417)}{0.6993}\, D_t^{**} + \underset{(0.0624)}{0.6266} \ln\left(\frac{T}{N}\right)^{**} + \underset{(0.0365)}{0.1487} \ln\left(\frac{F}{N}\right)^{**} + \underset{(0.0029)}{0.0175} \ln\left(\frac{E}{N}\right)^{**} \quad \ldots 10$$

$$R^2 \text{ (adj)} = 0.4319$$
$$\text{SEE} = 0.2947$$

The dummy variable D_t has a value of one for the technological stratum HYM 1 and zero otherwise. The coefficient of D_t is positive and is significant at the 1% level. Its numerical value of 0.6993 implies that the multiplicative constant term of the HYM 1 function is higher by 101% compared with the corresponding value in the function for USM, shown in *Equations 11* and *12*. Thus, there is a 101% upward shift of the production function for HYM 1 relative to USM.

Using the same set of data, Yee[9] has shown that the nature of the shift in the production function between USM and HYM 1 technological strata was neutral. It is possible in the present analysis to obtain separate equations for the production functions of the USM and the HYM 1 technological strata based on the intercept term and the coefficient of D_t of *Equation 10.* The separate production functions for the USM and the HYM 1 technological strata are given in *Equations 11* and *12* respectively:

$$Y_{\mathrm{USM}} = 1.2076\, N^{0.2072}\, T^{0.6266}\, F^{0.1487}\, E^{0.0175} \quad \ldots 11$$

$$Y_{\mathrm{HYM\,1}} = 2.4303\, N^{0.2072}\, T^{0.6266}\, F^{0.1487}\, E^{0.0175} \quad \ldots 12$$

The power of N (*i.e.* α_1) in the above equations is derived implicitly from the estimates of *Equation 10* where $\alpha_1 = 1 - \alpha_2 - \alpha_3 - \alpha_4$.

Estimates of the derived input demand functions in N, T, F and E for the USM and HYM 1 technological strata have been obtained by substituting the regression coefficients of *Equations 11* and *12* respectively into the N, T, F and E input demand functions given by *Equations 4* to *7.* These results are presented in *Table 2.*

The shift in the per hectare input demand function between the USM and the HYM 1 technological strata can be computed by substituting for Y at the observed geometric mean output per hectare for the respective technologies and multiplying by the respective observed mean output prices. The geometric mean output per hectare of USM and HYM 1 are 540 kg and 1241 kg respectively. The mean output prices are the same for both the USM and HYM 1 strata and hence are cancelled out in the computation process. These computations indicate that the shift for each input demand function (*i.e.* N, T, F and E) resulting from the introduction of HYM 1 technology is about 12%. The upward shift in the input demand functions for the HYM 1 technological stratum as compared to the USM technological stratum implies that the adoption of HYM 1 technology increased the demand for all inputs at the given factor prices by about 12%.

The upward shift of the input demand functions resulting from introduction of HYM 1 technology could have been

TABLE 2. ESTIMATES OF DERIVED INPUT DEMAND FUNCTIONS FOR USM AND HYM 1 TECHNOLOGICAL STRATA

Demand function	Multiplicative constant		Coefficient of				
	USM	HYM 1	Y	P_n	P_t	P_f	P_e
Labour (N)	0.4541	0.2256	1	−0.7928	0.6266	0.1487	0.0175
Tree (T)	1.3732	0.6824	1	0.2072	−0.3734	0.1487	0.0175
Fertiliser (F)	0.3259	0.1619	1	0.2072	0.6266	−0.8513	0.0175
Other input expenditure (E)	0.0384	0.0191	1	0.2072	0.6266	0.1487	−0.9825

largely due to the fact that the USM fields were old and were due for replanting. This effect cannot be attributed to be variable *T*, because while *T* is an age corrected tree variable, it is constructed separately for each type of technological stratum. The level of inputs employed in these USM fields was likely to have been low because the output response to higher input applications was not expected to be high as these fields were planted with low-yielding and unselected seedlings. On the other hand, HYM 1 fields consisted of young and high-yielding trees which are responsive to higher input applications as recommended by the research stations. Therefore, a higher level of input was employed in HYM 1 fields.

Derived input demand functions for high-yielding technological strata. The nature and degree of change in the input demand functions among the high-yielding technological strata have been estimated separately for production years 1964, 1970 and 1976. Restricting the production function estimates to constant returns to scale, the function on pooled data of HYM 1, HYM 2 and HYM 3 for each of the three years 1964, 1970 and 1976 are presented by *Equations 13, 14* and *15* respectively:

$$\ln\left(\frac{Y}{N}\right) = 1.1631 + \underset{(0.0471)}{0.1034}\, D_1^{**} + \underset{(0.0547)}{0.1937}\, D_2^{**} + \underset{(0.0946)}{0.5894} \ln\left(\frac{T}{N}\right)^{**} + \underset{(0.0611)}{0.1194} \ln\left(\frac{F}{N}\right)^{**} + \underset{(0.0411)}{0.0691} \ln\left(\frac{E}{N}\right)^{**} \qquad \ldots 13$$

R^2 (adj) = 0.4194
SEE = 0.2811

$$\ln\left(\frac{Y}{N}\right) = 1.3142 + \underset{(0.0412)}{0.1217}\, D_1^{**} + \underset{(0.0614)}{0.2487}\, D_2^{**} + \underset{(0.0718)}{0.5933} \ln\left(\frac{T}{N}\right)^{**} + \underset{(0.0291)}{0.1328} \ln\left(\frac{F}{N}\right)^{**} + \underset{(0.0113)}{0.0411} \ln\left(\frac{E}{N}\right)^{**} \qquad \ldots 14$$

R^2 (adj) = 0.3314
SEE = 0.3010

$$\ln\left(\frac{Y}{N}\right) = 0.8147 + \underset{(0.0247)}{0.1774}\, D_1^{**} + \underset{(0.0381)}{0.2766}\, D_2^{**} + \underset{(0.0517)}{0.5249} \ln\left(\frac{T}{N}\right)^{**} + \underset{(0.0691)}{0.1138} \ln\left(\frac{F}{N}\right)^{**} + \underset{(0.0314)}{0.0744} \ln\left(\frac{E}{N}\right)^{**} \qquad \ldots 15$$

R^2 (adj) = 0.3876
SEE = 0.2574

In these three equations D_1 and D_2 are the technological dummy variables with a value of 1 for HYM 2 and HYM 3 respectively, and of zero otherwise. The production function estimates for HYM 1, HYM 2 and HYM 3 for the production years 1964, 1970 and 1976 respectively have been derived from these equations and are presented in *Table 3*. The equations of *Table 3* assumed constant returns to scale with respect to the input of harvesting labour, trees, fertilisers and other input expenditure. The input demand functions for N, T, F and E of each technological stratum are obtained by substituting the production coefficients of the respective regressions in the demand functions in *Equations 4* to *7*. The results are presented in *Table 4*. By substituting the observed geometric mean output per hectare for Y in the respective technological strata and for each year, the per hectare demand functions for N, T, F and E can be obtained. The geometric sample mean output per hectare for 1964 are: HYM 1 = 1241 kg, HYM 2 = 1286 kg and HYM 3 = 1398 kg; 1970: HYM 1 = 1312 kg, HYM 2 = 1350 kg and HYM 3 = 1511 kg and 1976: HYM 1 = 1473 kg, HYM 2 = 1502 kg and HYM 3 = 1664 kg). These computations indicate that the per hectare demand functions for the HYM 1, HYM 2 and HYM 3 have shifted by the following magnitudes:

with respect to the 1964 data set,

HYM 1 → HYM 2 = –6.54%
HYM 2 → HYM 3 = –0.69%
HYM 1 → HYM 3 = –7.23%

with respect to the 1970 data set,

HYM 1 → HYM 2 = –8.89%
HYM 2 → HYM 3 = –1.37%
HYM 1 → HYM 3 = –10.26%

with respect to the 1976 data set,

HYM 1 → HYM 2 = –14.61%
HYM 2 → HYM 3 = –0.32%
HYM 1 → HYM 3 = –14.93%

TABLE 3. PRODUCTION FUNCTIONS FOR HYM 1, HYM 2 AND HYM 3 BY YEARS

Year	Technological stratum	Production function estimates				
1964	HYM 1	Y = 3.1998	$N^{0.2221}$	$T^{0.5894}$	$F^{0.1194}$	$E^{0.0691}$
	HYM 2	Y = 3.5484	$N^{0.2221}$	$T^{0.5894}$	$F^{0.1194}$	$E^{0.0691}$
	HYM 3	Y = 3.8837	$N^{0.2221}$	$T^{0.5894}$	$F^{0.1194}$	$E^{0.0691}$
1970	HYM 1	Y = 3.7218	$N^{0.2328}$	$T^{0.5933}$	$F^{0.1328}$	$E^{0.0411}$
	HYM 2	Y = 4.2034	$N^{0.2328}$	$T^{0.5933}$	$F^{0.1328}$	$E^{0.0411}$
	HYM 3	Y = 4.7698	$N^{0.2328}$	$T^{0.5933}$	$F^{0.1328}$	$E^{0.0411}$
1976	HYM 1	Y = 2.2585	$N^{0.2869}$	$T^{0.5249}$	$F^{0.1138}$	$E^{0.0744}$
	HYM 2	Y =2.6969	$N^{0.2869}$	$T^{0.5249}$	$F^{0.1138}$	$E^{0.0744}$
	HYM 3	Y = 2.9782	$N^{0.2869}$	$T^{0.5249}$	$F^{0.1138}$	$E^{0.0744}$

TABLE 4. ESTIMATES OF DERIVED INPUT DEMAND FUNCTIONS FOR HYM 1, HYM 2 AND HYM 3 BY YEARS

Year	Demand function	Multiplicative constant			Coefficient of				
		HYM 1	HYM 2	HYM 3	Y	P_n	P_t	P_f	P_e
1964	N	0.2052	0.1851	0.1691	1	−0.7779	0.5894	0.1194	0.0691
	T	0.5446	0.4911	0.4488	1	0.2221	−0.4106	0.1194	0.0691
	F	0.1103	0.0995	0.0909	1	0.2221	0.5894	−0.8806	0.0691
	E	0.0639	0.0576	0.0526	1	0.2221	0.5894	0.1194	−0.9309
1970	N	0.1785	0.1580	0.1392	1	−0.7672	0.5933	0.1328	0.0411
	T	0.4548	0.4027	0.3549	1	0.2328	−0.4067	0.1328	0.0411
	F	0.1018	0.0901	0.0794	1	0.2328	0.5933	−0.8672	0.0411
	E	0.0315	0.0279	0.0246	1	0.2328	0.5933	0.1328	−0.9589
1976	N	0.3961	0.3317	0.3003	1	−0.7131	0.5249	0.1138	0.0744
	T	0.7247	0.6069	0.5495	1	0.2869	−0.4751	0.1138	0.0744
	F	0.1571	0.1315	0.1191	1	0.2869	0.5249	−0.8862	0.0744
	E	0.1027	0.0860	0.0779	1	0.2868	0.5249	0.1138	−0.9256

The minus sign implies a downward shift for the input demand functions of *N, T, F* and *E* as one moves from an older technological stratum to a newer one. It must be noted that the above computations are made based on the observed physical per hectare mean of the output *Y* for each year and the price of *Y* for each year is assumed to be constant for each technological stratum.

A comparison of the various input demand functions among the HYM technological strata for each of the 1964, 1970 and 1976 production years reveals the opposite result to that obtained in the case of the shift from USM to HYM 1 technology as revealed in the 1964 data. The general pattern for the high-yielding technological strata for each of the three years is that the downward shift between HYM 1 and HYM 2 is relatively large while the shift from HYM 2 to HYM 3 is relatively small. In addition, the overall magnitude of the downward shift from HYM 1 to HYM 3 for the input demand functions of *N, T, F* and *E* is found to be increasing as one proceeds from 1964 to 1970 to 1976. One possible reason is that when HYM 2 and HYM 3 were introduced after World War II, research results and managerial experience gradually established many techniques by which the need for conventional inputs could be reduced (minimising production cost) while still maintaining high productivity.

Empirical Estimates of Cost Functions

The extent to which the long-run cost functions have shifted as a result of the introduction of high-yielding cultivars and their associated package of improved technologies is examined in this section. For purposes of empirical estimation, the reduced form cost function given by *Equation 9* has been further simplified because the relevant price data for the variable E were not available. This is because variable E consisted of many miscellaneous items and a meaningful standardised price variable could not be constructed. To overcome the problem of deriving an arbitrary price variable P_e, *Equation 9* has been rewritten as:

$$\ln TC = \ln A^* + 1/\gamma \ln Y + \alpha_1/\gamma \ln P_n + \alpha_2/\gamma \ln P_t + \alpha_3/\gamma \ln P_f - \delta/\gamma - \mu/\gamma \quad \ldots 16$$

where TC is total production cost per field in Malaysian ringgit

P_n is wage rate per man-day harvesting labour. (This value is derived by dividing the total wage bill of the sample field by the total number of man-days of harvesting labour.)

P_t is price per tree corrected for age effect. P_t is defined as equivalent to the index value of a rubber tree, V_t.

P_f is average price of fertilisers. (This is computed by taking the total fertiliser bill of the field and dividing it by the quantities used per field.)

Y is output of rubber in RSS 1 equivalent per field

$$\ln A^* = \ln A + (\alpha_4/\gamma) \ln P_e$$

Because $\gamma = \alpha_1 + \alpha_2 + \alpha_3 + \delta_4$, and an estimate of γ is provided from the coefficient of $\ln Y$ in *Equation 16*, the output elasticity with respect to variable E can be derived. One would expect that the modified form of cost function in *Equation 16* would impart a certain degree of specification bias to the estimated coefficients of N, T, and F[10]. Thus, when the empirical results of *Equation 16* are obtained, care must be exercised in interpreting the parameters *(Appendix A)*.

Empirical cost functions for USM and HYM 1. Results of the least-squares estimates of *Equation 16* for USM and HYM 1 and the pooled data are presented in *Table 5.* The estimate of the term $-\delta/\gamma$ is -0.5133. This value is significant at the 1% level. In terms of the percentage shift between the two functions, the negative value implies that the introduction of the high-yielding technological stratum, HYM 1, has resulted in a downward shift of the long-run cost function of the order of 67%. An analysis of covariance was used to test the hypothesis of equality between the slope coefficients of regression $R1.1$ and $R1.2$. If the null hypothesis of equal slopes is accepted, one can infer that the shift of the cost functions is neutral in nature. Comparing separate regressions of $R1.1$ (USM) and $R1.2$ (HYM 1) with the regression on pooled data $R1.4$ (estimated with the constraint of slope homogeneity), the computed F_2 value with 3 and 474 degrees of freedom is 1.69, which is not significant at the 5% level. These results, therefore, suggest that the shift of 67% is of a neutral nature.

Empirical comparisons of cost functions among high-yielding technological strata. In this section, estimates are obtained of the nature and magnitude of the shift in the long-run cost functions when HYM 1 is replaced by HYM 2 and when HYM 2 is replaced by HYM 3 technology.

Least squares regression estimates of cost functions for the various high-yielding technological strata for the years 1964, 1970 and 1976 are presented in *Tables 6, 7* and *8* respectively. In each case, over 90% of the variation in the logarithms by total production cost ($\ln TC$) is explained by the independent variables $\ln Y$, $\ln P_n$, $\ln P_t$ and $\ln P_f$. In addition, most of the coefficients of the independent variables are different from zero at the 1% significant level indicating that

TABLE 5. ESTIMATES OF COST FUNCTIONS FOR USM, HYM 1 AND POOLED DATA, 1964

Variable	USM (R1 .1)	HYM 1 (R1 .2)	Pooled (R1 .3)	Pooled (R1 .4)
Output (Y)	0.8479** (0.0333)	0.9183** (0.0913)	0.8816** (0.0242)	0.9104** (0.0238)
Harvesting labour price (P_n)	0.1781** (0.0616)	0.2581** (0.1147)	0.2737** (0.1380)	0.1811* (0.1011)
Tree price (P_t)	0.5469** (0.2362)	0.5717** (0.2177)	0.3556** (0.0872)	0.5817** (0.0929)
Fertiliser price (P_f)	0.1832* (0.1015)	0.1247** (0.0817)	0.1986** (0.0952)	0.2111** (0.0934)
Technological dummy (D_t)				–0.5133** (0.0563)
Intercept (A)	2.5511	–1.7923	0.3214	–0.8779
Adjusted R^2	0.8554	0.9229	0.7735	0.8875
SEE	0.3365	0.2590	0.4267	0.3090
Returns to scale	1.1794	1.0889	1.1343	1.0984
No. of fields	98	384	482	482

Figures within brackets are standard errors of the coefficients.

Standard error of estimates (SEE) are in natural logarithms of total cost of production per field in ringgit.

Returns to scale is derived by taking the reciprocal of output coefficient $(\frac{1}{\gamma})$

*Significant at the 5% level

**Significant at the 1% level

the basic model in *Equation 16* is a good fit to the various data sets.

The magnitude of returns to scale with respect to various conventional input factors is derived by taking the reciprocal of the coefficient of logarithms of rubber output Y (*i.e.* $1/\gamma$). These values centre around unity for all functions in *Tables 6, 7* and *8*, in conformity with the results obtained by the production function approach[9]. However, estimated returns to scale are higher than those derived by the production function approach, perhaps due to the omission of the P_e variable in the cost function model causing a downward bias of the coefficient of the logarithm of output Y $(1/\gamma)$ which in turn caused an upward bias in the returns to scale estimate (γ) *(Appendix A)*.

An analysis of covariance has been carried out for each technological stratum to determine the nature of shift for the long-run cost functions between HYM 1, HYM 2 and HYM 3 (as shown in *Tables 6, 7* and *8*), and the results are presented in *Table 9*. These results suggest that the shifts in the long-run cost functions between HYM 1, HYM 2 and HYM 3 are neutral in nature for production years 1964, 1970 and 1976. Thus the difference between the cost functions of different high-yielding technological strata for

TABLE 6. ESTIMATES OF COST FUNCTIONS FOR HYM 1, HYM 2, HYM 3 AND POOLED DATA, 1964

Variables	HYM 1 (R1 .2)	HYM 2 (R2 .1)	HYM 3 (R2 .2)	Pooled (R2 .3)	Pooled (R2 .4)
Output (Y)	0.9183** (0.0913)	0.9604** (0.0818)	0.9447** (0.0314)	0.9305** (0.0177)	0.9541** (0.0414)
Harvesting labour price (P_n)	0.2581** (0.1147)	0.2078** (0.1136)	0.2277** (0.0819)	0.2576** (0.0614)	0.2296** (0.0429)
Tree price (P_t)	0.5717* (0.2177)	0.6497** (0.1292)	0.7211** (0.0114)	0.9141** (0.0174)	0.5941** (0.2123)
Fertiliser price (P_f)	0.1247* (0.0817)	0.0894** (0.0117)	0.1047* (0.0617)	0.0419 (0.0481)	0.1141* (0.0616)
Technology dummy (D_1)					–0.1347** (0.0217)
Technology dummy (D_2)					–0.1971** (0.0319)
Intercept (A)	–1.7923	–1.8303	–2.0471	–3.1098	–1.9879
Adjusted R^2	0.9229	0.8903	0.9166	0.9704	0.9181
SEE	0.2590	0.2646	0.2541	0.2637	0.2547
Returns to scale	1.0889	1.0412	1.0585	1.0747	1.0481
No. of fields	384	277	152	813	813

Figures within brackets are standard errors of the coefficients.

Standard error of estimates (SEE) are in natural logarithms of total cost of production per field in ringgit.

γ measures physical returns to scale and is derived from the reciprocal of the coefficients of the ln Y.

*Significant at the 5% level

**Significant at the 1% level

all the three production years is due to changes in the intercept terms and not changes in the sets of slope coefficients.

The magnitude of the neutral shift between different cost functions can be measured by the estimated coefficients of the dummy variables; D_1 and D_2 have the value of one for the years 1970 and 1976 and of zero otherwise for *Tables 6, 7* and *8*. Since the coefficients of D_1 and D_2 are negative for all three samples, the cost functions of HYM 2 and HYM 3 have moved downwards relative to the HYM 1 cost function for each year. For example, in production year 1964, the intercepts of the HYM 2 and HYM 3 differed by the values of -0.1349 and -0.1971 respectively compared to HYM 1. Since the shift is neutral in nature, the use of HYM 2 and HYM 3 in 1964 production year shifted the long-run cost functions of HYM 2 and HYM 3 downwards by 14.42% and 21.79% respectively, compared to HYM 1 long-run cost function. Similar interpretations can also be made for the production years 1970 *(Table 7)* and 1976 *(Table 8)*.

TABLE 7. ESTIMATES OF COST FUNCTIONS FOR HYM 1, HYM 2, HYM 3 AND POOLED DATA, 1970

Variable	HYM 1 (R3 .1)	HYM 2 (R3 .2)	HYM 3 (R3 .3)	Pooled (R3. 4)	Pooled (R3 .5)
Output (Y)	0.8919** (0.0714)	0.9322** (0.0947)	0.9114** (0.0639)	0.8994** (0.1033)	0.9288** (0.0913)
Harvesting labour price (P_n)	0.2247** (0.0977)	0.2631 (0.1231)	0.1944** (0.1011)	0.1843** (0.0714)	0.2391** (0.0861)
Tree price (P_t)	0.4977** (0.1234)	0.5214** (0.1011)	0.5369** (0.0814)	0.5113** (0.0974)	0.5285** (0.1147)
Fertiliser price (P_f)	0.0993* (0.0581)	0.1124** (0.0301)	0.1218** (0.0421)	0.1022* (0.0599)	0.1164** (0.0384)
Technology dummy (D_1)					−0.1138** (0.0297)
Technology dummy (D_2)					−0.1321** (0.0314)
Intercept (A)	−1.2144	−1.8143	−1.0477	0.1377	−0.7241
Adjusted R^2	0.9139	0.9411	0.9213	0.9147	0.9317
SEE	0.2144	0.2003	0.2094	0.2103	0.2109
Returns to scale	1.1212	1.0727	1.0972	1.1118	1.0766
No. of fields	197	300	213	710	710

Figures within brackets are standard errors of the coefficients.

Standard error of estimates (SEE) are in natural logarithms of total cost of production per field in ringgit.

γ measures physical returns to scale and is derived from the reciprocal of the coefficients of the ln Y.

*Significant at the 5% level

**Significant at the 1% level.

Implications and Conclusions

The reduced form of input demand functions provides quantitative assessment of the extent of the shifts in the input demand functions with respect to all input factors. The results of the analysis indicate that there is a 12% upward shift (increase in quantity consumed for a given price) in the derived input demand functions for all the input factors (labour, tree, fertiliser and other input expenditure) when the HYM 1 technology is substituted for the USM technology. It must be emphasised that resource constraints were not the major criteria when the HYM 1 technology was developed. A 12% upward shift in the labour demand function resulting from the introduction of HYM 1 technology would have been a significant step towards increasing employment at a time when labour was in plentiful supply. An upward shift of about 12% in the derived tree demand function implied higher usage of trees planted per hectare of land, with subsequent greater usage of harvesting

TABLE 8. ESTIMATES OF COST FUNCTIONS FOR HYM 1, HYM 2, HYM 3 AND POOLED DATA, 1976

Variable	HYM 1 (R4 .1)	HYM 2 (R4 .2)	HYM 3 (R4 .3)	Pooled (R4 .4)	Pooled (R4 .5)
Output (Y)	*0.9311*** (0.1131)	*0.9149*** (0.0817)	*0.9211*** (0.0927)	*0.8979*** (0.1013)	*0.9293*** (0.0924)
Harvesting labour price (P_n)	0.1984** (0.0723)	0.1993** (0.0914)	0.2139** (0.1011)	0.2039** (0.0914)	0.2109** (0.0876)
Tree price (P_t)	0.4873** (0.1032)	0.5344** (0.0976)	0.5149** (0.1011)	0.5044** (0.0981)	0.5201** (0.0814)
Fertiliser price (P_f)	0.1421** (0.0317)	0.1327** (0.0416)	0.1149* (0.0624)	0.1038** (0.0391)	0.1397** (0.0417)
Technology dummy (D_1)					–0.1974** (0.0691)
Technology dummy (D_2)					–0.2144** (0.0819)
Intercept (A)	0.1047	–0.3217	0.5144	1.3217	–0.2977
Adjusted R^2	0.9133	0.9347	0.9458	0.9359	0.9511
SEE	0.2204	0.2101	0.1993	0.2100	0.1877
Returns to scale	1.0739	1.0930	1.0856	1.1137	1.0761
No. of fields	108	224	287	619	619

Figures within brackets are standard errors of the coefficients.

Standard error of estimates (SEE) are in natural logarithms of total cost of production per field in ringgit.

γ measures physical returns to scale and is derived from the reciprocal of the coefficients of the $\ln Y$.

*Significant at the 5% level

**Significant at the 1% level

labour. However, this result must be interpreted with caution because fields under the USM technology were mostly old rubber trees. As such, the tapping density was very much below the original tappable stand. The upward shift in the derived fertiliser demand function would have stimulated the development of local fertiliser manufacturing sector which, in turn, contributed to the development of the industrial sector in the country. The upward shift in the derived input lemand function for the other input expenditure suggested that a higher cash input for maintenance and miscellaneous expenditure was needed when the HYM 1 technology was introduced.

A different trend emerged when the more recent technologies (*i.e.* HYM 2 and HYM 3) were compared with the HYM 1 technology. Empirical results indicated that the derived input demand functions for all input factors were found to have shifted downwards when the HYM 2 and HYM 3 technologies were substituted for the HYM 1 technology. These downward shifts in the various derived input demand functions suggested

TABLE 9. RESULTS OF COVARIANCE ANALYSIS FOR HIGH-YIELDING TECHNOLOGICAL STRATA, 1964, 1970 AND 1976 SAMPLES

Production year	Degree of freedom (n_1 ; n_2)	F value
1964	2;806	F_1 = 3.14**
(Table 11.6)	8;798	F_2 = 0.98
	10;798	F_3 = 21.32**
1970	2;703	F_1 = 8.36**
(Table 11.7)	8;695	F_2 = 1.34
	10;695	F_3 = 5.76**
1976	2;612	F_1 = 5.17**
(Table 11.8)	8;604	F_2 = 1.93
	10;604	F_3 = 9.77**

**Significant at the 1% level

that technological advances have reduced the demand for inputs at given prices while at the same time increasing productivity. It is probable that with a move from HYM 1 to HYM 2 technology and from HYM 2 to HYM 3 technology, the higher yielding characteristics inherent in the genetic components of the newly introduced cultivars gave increased productivity while improvements in the associated package of technology resulted in less usage of input factors due to increased production efficiency. The empirical evidence thus revealed that recent technological advances have been moving in the appropriate direction with respect to the current constraints on labour and the increasing cost of other inputs in the Malaysian rubber growing industry.

Long-run cost functions associated with HYM technological strata were found to have shifted downwards in the 1964, 1970 and 1976 production years. Empirical analysis revealed a neutral downward shift of the long-run cost function of about 67% when HYM 1 technology was introduced to replace USM technology. Further results indicated that when the more recent high-yielding technologies of HYM 2 and HYM 3 were introduced there was a further downward and neutral shift in the long-run cost functions indicating that the production cost per unit of rubber output has been substantially reduced. However, these empirical results also indicated that the magnitude of these downward shifts was relatively small compared with the 67% gains achieved by the introduction of HYM 1 to replace USM technology. The important implication is that the rate of reduction in the cost per unit of output resulting from the introduction of the recent high-yielding technologies (HYM 2 and HYM 3) has been diminishing given the existing factor prices.

Technological developments which have occurred in the past have played an important role in the Malaysian rubber industry, increasing productivity and reducing unit production costs. The empirical results on factor input demand and cost functions presented in this paper suggest that past research has not been biased in favour of one or more inputs.

Furthermore, research has led to technological changes which have lowered the unit cost of raw rubber production. The evidence presented implies that gains from research along the same lines as in the past appear to have been diminishing over time. In addition, the increasing cost of labour may require future research to be deliberately biased towards labour saving technology. For these two reasons, future rubber group research policies may need to be very different from those of the past.

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Ordinary least squares estimation applied to *Equation 16* yields six coefficent estimates, the first one being of limited importance, because the remaining five estimates are sufficient for the determination of α_1, α_2, α_3, α_4 and δ. These last five coefficients also occur in the true *Equation 9,* from which *Equation 16* is derived. Of concern is how different the estimates derived from *Equation 16* would be from estimates derived from *Equation 9* if data on $\ln P_e$ were available. An attempt is made here to redress this problem by appealing to the methods of specification analysis.

To examine this in more detail, let

(1) $\tilde{X} = (1 \ \ln Y \ \ln P_n \ \ln P_t \ \ln P_f \ d)_{n x 6}$

where 1 is an n X 1 vector of ones, d is the dummy variable whose coefficient is $-\delta/\gamma$, and n is the number of observations. The application of ordinary least squares to *Equation 16* yields

(2) $\tilde{\theta} = (\tilde{X}'\tilde{X})^{-1} X'X\beta + (\tilde{X}'\tilde{X})^{-1} X \ \mu$

where $\ln TC = X\beta + \mu$ is the true model in *Equation 9.* Hence, if X is a nonstochastic matrix, as is assumed, then $E(\tilde{X}'\tilde{X})^{-1} \ X \ \mu = 0$ and so $E(\tilde{\theta}) = E[(\tilde{X}'\tilde{X})^{-1} \ \tilde{X}'X] \ \beta$. The expression $[(\tilde{X}'\tilde{X})^{-1} \ \tilde{X}'X]$ is a 6 X 7 matrix, containing information on the specification bias included by using *Equation 9* to estimate the coefficients, β, of *Equation 16.* This matrix, [ ], contains seven columns, each one consisting of the six least squares estimates derived from regressing, in turn, the variables in X on all six variables in X. As X and X differ only in the insertion of $\ln P_e$ into X, then the columns of [ ] will consist of a single unit and zeros, except for the sixth column, which contains six regression coefficients, $\hat{\eta}$; derived by regression $\ln P_e$ on $[1 \ln Y \ln P_n \ \ln P_t \ \ln P_f d]$. The matrix [ ] can be written as

$$(3) \ [\ \ ] = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & \hat{\eta}_1 & 0 \\ 0 & 1 & 0 & 0 & 0 & \hat{\eta}_2 & 0 \\ 0 & 0 & 1 & 0 & 0 & \hat{\eta}_3 & 0 \\ 0 & 0 & 0 & 1 & 0 & \hat{\eta}_4 & 0 \\ 0 & 0 & 0 & 0 & 1 & \hat{\eta}_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & \hat{\eta}_6 & 1 \end{bmatrix}$$

Therefore,

$$(4) \ E(\hat{\theta}) = E[\ ] \ \beta = \begin{bmatrix} \ln A \\ 1/\gamma \\ \alpha_1/\gamma \\ \alpha_2/\gamma \\ \alpha_3/\gamma \\ -\delta/\gamma \end{bmatrix} + \alpha_4]\gamma.E \begin{bmatrix} \hat{\eta}_1 \\ \hat{\eta}_2 \\ \hat{\eta}_3 \\ \hat{\eta}_4 \\ \hat{\eta}_5 \\ \hat{\eta}_6 \end{bmatrix}$$

The terms $E(\hat{\eta}_3)$, $E(\hat{\eta}_4)$ and $E(\hat{\eta}_5)$ can be expected to be small, as $\ln P_e$ is thought to be uncorrelated with the prices of other inputs, as stated earlier. Also $E(\hat{\eta}_6)$ will be small, as dummy variable d will not be related to $\ln P$. But more interestingly, any relationship, if it exists, between a price index (or its logarithm) constructed to represent miscellaneous expenses and the total output (or its logarithm) of an estate is likely to be an inverse one. The larger a rubber plantation is, the more able it is to avail itself of reduced per unit input costs, through bulk discounts, access to market information, cash purchases, *etc.* As a result the term $E(\hat{\eta}_2)$, if other than zero, is more likely to be negative than positive. Hence, as α_4 and γ are positive constants, from (4), the second element of $E(\hat{\theta})$ is equal to $1/\gamma$ minus some value, confirming that there is an upward bias in the estimates of the returns to scale.